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(54) Spacecraft deployment mechanism damper

(57) The present invention provides an electrorheological magnetic (ERM) fluid-based rotary motion damper (12). According to the invention, the ERM fluid-based rotary motion damper (12) generally includes an input shaft (18) coupled to a first damping member (16) and rotatably supporting a second damping member (20). A cylinder (28) coupled about the first damping member (16) rotatably engages a housing (36) circumferentially coupled about the second damping member (20). As such, the cylinder (28) is configured for rotary movement relative to the housing (36). ERM fluid (56) disposed in the housing (36) surrounds the cylinder (28) such that it coacts with the housing (36) and cylinder (28). In the presence of a magnetic field, the ERM fluid (56), cylinder (28) and housing (36) frictionally control the rotary movement of the first damping member (16) relative to the second damping member (20).

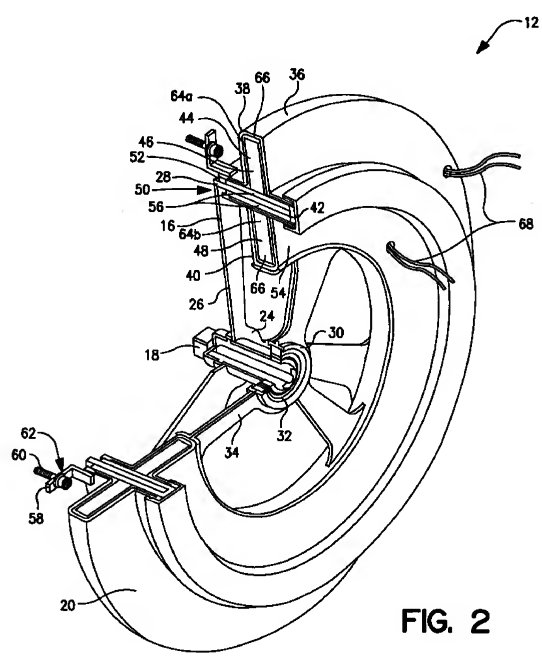

FIG. 2

EP 0 872 665 A1

Description

BACKGROUND OF THE INVENTION

1. Technical Field

The present invention is generally related to damper mechanisms and, more particularly, to an electrorheological magnetic (ERM) fluid-based damper for controlling the deployment and operation of spacecraft appendages such as solar array panels, antennas, optical platforms, and other spacecraft structural elements.

2. Discussion

Deployment of spacecraft appendages such as antenna dishes, solar panel arrays, etc. are mission-critical operations that must be accomplished reliably and in a controlled fashion without causing damage or excessive disturbances and oscillations in the spacecraft. Conventional spacecraft typically use magnetic-type devices for deployment mechanisms. These devices include controllable electric motors and damper devices known as "eddy current" dampers

In light of recent deployment problems, civilian and defense spacecraft customers are requiring torque margins for deployment mechanisms many times greater than earlier levels. This torque margin, as well as the revised requirements for damping rate, response time, and control, are beyond the capabilities of the typical presently used damper and control devices. Thus, the enhanced requirements have created a need for more powerful deployment mechanisms with much greater damper and control system performance.

It has now been found desirable to utilize electrorheological magnetic (ERM) fluid for enhanced damping control. ERM fluids undergo a change in apparent viscosity when subjected to a magnetic field. In the presence of a magnetic field, the particles become polarized and are thereby organized into chains and columns of particles within the fluid. The chains and columnar arrangement of particles act to increase the apparent viscosity or flow resistance of the overall material. In the absence of a magnetic field, the particles return to an unorganized or free state and the apparent viscosity or flow resistance of the overall material is correspondingly reduced.

Due to its variable resistance, ERM materials have been found useful in providing varying damping forces as well as in controlling torque and/or pressure levels. ERM fluids exhibit high yield strengths and are capable of generating great damping forces. Furthermore, ERM materials are activated by magnetic fields which are easily produced by simple, low-voltage electromagnetic coils.

Accordingly, it would be desirable to provide a deployment mechanism employing an ERM fluid based damper capable of meeting advance spacecraft requirements. The ERM damper could be used to control the driving force or torque of a reliable spring or motor-driven actuator. Furthermore, it would be desirable to provide an ERM damper capable of Fixed or variable damping control or a combination thereof.

SUMMARY OF THE INVENTION

The above and other objects are provided by an electrorheological magnetic (ERM) fluid-based rotary motion damper. The ERM fluid-based rotary motion damper generally includes an input shaft coupled to a first damping member and rotatably supporting a second damping member. A cylinder coupled about the first damping member rotatably engages a housing circumferentially coupled about the second damping member. As such, the cylinder is configured for rotary movement relative to the housing. ERM fluid disposed in the housing surrounds the cylinder such that it coacts with the housing and cylinder. In the presence of a magnetic field, the ERM fluid, cylinder and housing frictionally control the rotary movement of the first damping member relative to the second damping member.

BRIEF DESCRIPTION OF THE DRAWINGS

In order to appreciate the manner in which the advantages and objects of the invention are obtained, a more particular description of the invention will be rendered by reference to specific embodiments thereof which are illustrated in the appended drawings. Understanding that these drawings only depict preferred embodiments of the present invention and are not therefore to be considered limiting in scope, the invention will be described and explained with additional specificity and detail through the use of the accompanying drawings in which:

FIG. 1 is a perspective view of a spring-driven spacecraft appendage deployment mechanism with a partially cut away ERM fluid damper incorporated therein in accordance with the teachings of the present invention;

FIG. 2 is a side perspective view in partial cross-section of an electromagnetic ERM damper device for actively controlling damping;

FIG. 3 is a side perspective view in partial cross-section of a permanent magnetic ERM damper device for providing passive damping; and

FIG. 4 is a side perspective view in partial cross-section of an integrated electro/permanent magnet ERM damper device.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

The present invention is directed toward a superior performance deployment mechanism capable of meet-

ing advanced spacecraft requirements including an electrorheological magnetic (ERM) fluid based damper in combination with a reliable spring or motor-driven actuator. The ERM damper contains a fluid responsive to a magnetic field for controlling the driving force or torque of the actuator. Application of a magnetic field to the ERM fluid increases its shear stress which is used to resist the relative motion of two damping surfaces in contact with the fluid. In accordance with the teachings of the present invention, a fixed damping force for providing passively controlled damping or a variable damping force for providing actively-controlled damping is available.

Referring now to the figures, a deployment mechanism capable of meeting advanced spacecraft requirements is shown generally at 10. The deployment mechanism 10 includes an electrorheological magnetic fluid damper 12 in combination with a spring driven actuator 14. Although a spring driven actuator 14 is shown, it is to be understood that the ERM fluid damper 12 is also suitable for use in combination with other known actuators such as motor driven actuators.

Preferably, the ERM fluid damper 12 includes an inner rotatable member 16 coupled to an input shaft 18. Rotation of the input shaft 18 by the actuator 14 rotates the inner member 16. A stationary outer member 20 is rotatably supported about the input shaft 18 such that the input shaft 18 may rotate freely with respect to the outer member 20. The input shaft 18 is operably coupled to a wheel 22 of the spring driven actuator 14. Thus, the driving force or torque generated from the spring driven actuator 14 is conveyed to the damper 12 via the input shaft 18.

The deployment mechanism 10 also includes a second damper 12' disposed opposite the damper 12. The damper 12' may be identical to the damper 12 or may be an alternate embodiment thereof. In either case, the dampers 12 and 12' combine to dampen the actuator 14. It should be noted, however, that in some applications it may be desirable to only include one of the dampers 12 or 12'.

Turning now to FIG. 2, a more detailed view of a first embodiment of the ERM fluid damper 12 is shown. The inner rotatable member 16 includes a mounting hub 24 secured to the input shaft 18. A plurality of ribs or arms 26 radially project from the mounting hub 24 to an axially extending annular cylinder 28. The cylinder 28 is disposed in spaced-apart circumferential relation to the input shaft 18.

The outer member 20 includes a mounting hub 30 rotatably supported about the input shaft 18 such that the input shaft 18 may rotate freely therewithin. Preferably, this is accomplished by inserting a sleeve 32 between the input shaft 18 and the mounting hub 30. A plurality of ribs or arms 34 radially extend from the mounting hub 30 to support a hoop-shaped housing 36 circumferentially thereon. Preferably, the housing 36 has a generally cross-shaped cross-section including vertical chambers 38 and 40 and a horizontal chamber 42 therein.

As can be seen, the horizontal chamber 42 bisects the vertical chambers 38 and 40. The vertical chambers 38 and 40 are configured for supporting means 44 for generating a magnetic field across the horizontal chamber 42. For example, the vertical chamber 38 contains a first magnet 46 and the vertical chamber 40 contains a second magnet 48. The magnets 46, 48 are disposed in spaced relation across the horizontal chamber 42.

The horizontal chamber 42 includes an open end 50 adapted to receive the cylinder 28 of the inner member 16. In this way, the cylinder 28 may rotate within the housing 36 under the influence of the input shaft 18. Two O-rings 52 sealingly engage the cylinder 28 within the walls 54 of the horizontal chamber 42 to form a fluid tight compartment.

The horizontal chamber 42 is filled with ERM fluid 56 which substantially encompasses the cylinder 28. As such, a magnetic field may be generated across the horizontal chamber 42 from the magnets 46, 48 disposed in the vertical chambers 38 and 40. In the presence of the magnetic field, the shear stress of the ERM fluid 56 changes. In turn, the shear resistance of the ERM fluid 56 increases which serves to slow the rotation of the cylinder 28 within the housing 36. By changing this shear resistance, the rotation of the inner member 16 relative to the outer member 20 may be controlled. The controlled rotation of the inner member 16 is transferred to the input shaft 18 to dampen the actuator 14 (FIG.1).

An example of an ERM fluid which may be used in the spacecraft deployment mechanism 10 is described in U.S. Patent No. 5,354,488 to Shtarkman et al., which is assigned to the assignee of the present invention. Shtarkman discloses a fluid responsive to a magnetic field. The fluid comprises magnetizable particles, an oil vehicle, and a dispersant comprising small non-magnetizable dispersant particles which are insoluble in the vehicle. The magnetizable particles may be any suitable magnetizable materials such as iron, cobalt, nickel, their alloys, magnetic ferrites, and compounds of iron, nickel or cobalt with rare earth elements, chromium, silicon, boron, mixtures of the above, and certain magnetizable stainless steels. It should be noted that oil vehicles suitable for space applications generally have a low vapor pressure (e.g., less than 10^{-3}mm Hg (0.13 Pa) and remain liquidic over a wide temperature (preferably between -60° to 200°C).

A plurality of mounting brackets 58 may be spot-welded or otherwise fixedly secured to the exterior of the housing 36 for mounting the housing 36 to the wheel 22 (FIG. 1). A plurality of bolts 60 passing through apertures 62 in the mounting brackets 58 can be used effectively for this purpose. After mounting, the outer member 20 is held stationary about the rotating input shaft 18 with respect to the inner member 16.

In the embodiment shown in FIG. 2, an electromag-

net 64a is disposed within the vertical chamber 38. Likewise, an electromagnet 64b is disposed within the vertical chamber 40. A low power excitation coil 66 is provided proximate each electromagnet 64a and 64b for selectively generating the magnetic field. A pair of low voltage power/connector leads 68 extend through the housing 36 and electrically communicate with each coil 66 therein. Accordingly, electrically variable shear stress and actively controlled damping is provided. In some applications, it may also be desirable to integrate a sensor/controller system with feedback to coordinate the changes in the damping characteristics of the damper 12. It should be noted that the damper 12 can also be successfully operated with only one of the electromagnets 64a or 64b. Also, if both electromagnets 64a and 64b are employed for energizing the ERM fluid 56, each of the coils 66 should be arranged in such a way that opposite magnetic polarities are generated at the electromagnet poles.

Turning now to FIG. 3, a second embodiment ERM damper 12a is illustrated. This embodiment is essentially identical to the first embodiment except that the electromagnets 64a and 64b have been replaced by permanent magnets 70a and 70b within the vertical chambers 38 and 40. Additionally, the electronic hardware, i.e., excitation coils 66 and power/connector leads 68 associated with the electromagnets 64a and 64b, are omitted. The permanent magnets 70a and 70b generate a fixed magnetic field over the ERM fluid 56 in the horizontal chamber 42. As such, a pre-selected permanent flow resistance is provided within the damper 12a. Thus, passive control of the damping characteristics of the damper 12a is provided.

A third embodiment ERM damper 12b is illustrated in FIG. 4. In this embodiment, a combination of permanent magnets 70a and 70b and electromagnets 64a and 64b are disposed within the vertical chambers 38 and 40. As with the first embodiment, low power excitation coils 66 and low voltage power/connector leads 68 are provided for inducing a magnetic field from the electromagnets 64a and 64b. According to this configuration, a given flow resistance is provided within the damper 12b which may be ramped up by excitation of the electromagnets 64a and 64b. Thus, a combination passive damping control and active damping control device is provided. Preferably, light weight electromagnets 64a and 64b are utilized in both the first and third embodiments.

In operation, the spring driven actuator 14 is operated such that it deploys or asserts control over a given spacecraft appendage (generally indicated by the numeral 72). The input shaft 18 is rotationally driven by the actuator 14. In turn, the input shaft 18 rotates the inner member 16. The outer member 20, which is rotatably supported about the input shaft 18, remains stationary with respect to the input shaft 18 and inner member 16.

The cylinder 28, which is coupled to the inner member 16 rotates within the horizontal chamber 42 of the housing 36. The ERM fluid 56 within the horizontal chamber 42 interacts with the cylinder 28 and chamber walls 54 according to its flow resistance characteristics to frictionally effect the movement therebetween. This flow resistance is varied according to the magnetic field to which the ERM fluid 56 is subjected.

In the case of permanent magnets 70a and 70b, a fixed shear stress associated with the ERM fluid 56 dampens the rotation of the inner member 16 by a preselected amount. In the case of electromagnets 64a and 64b, either alone or in combination with the permanent magnets 70a and 70b, a variable damping of the inner member 16 occurs corresponding to the activation of the electromagnets 64a and 64b. As such, the rotary movement of the inner member 16 can be controlled by utilizing the variable shear stress characteristic of the ERM fluid 56.

From the foregoing it can be appreciated that the ERM damper directly transforms magnetic energy into mechanical energy without multiple mechanical stages. The dampers have a high output power-to-weight ratio and a fast (a few milliseconds) response time. Also, the dampers have a controllable and velocity-independent damping rate that permits near instantaneous application of high torque without the need for generating high rotational speeds. Additionally, the damper has the capability for both passive and active control with a high mechanical work output-to-electrical power ratio. The dampers are suitable for reliably and smoothly handling both slow and rapid deployment situations without causing disturbances or oscillations to spacecraft. The dampers are low-cost and simple to manufacture since they do not require precision machining or high-tolerance parts. The dampers are sealed devices which require only a very small quantity of space qualified fluid for reliable and low contamination risk operation.

Those skilled in the art can now appreciate from the foregoing description that the broad teachings of the present invention can be implemented in a variety of forms. Therefore, while this invention has been described in connection with particular examples thereof, the true scope of the invention should not be so limited since other modifications will become apparent to the skilled practitioner upon a study of the drawings, specification, and following claims.

Claims

1. A rotary damper for use in spacecraft appendage deployment mechanisms comprising:

   an input shaft;
   first member coupled to said input shaft;
   a second member rotatably supported about said input shaft,
   said first member being rotatable relative to said second member;

an electrorheological magnetic fluid coacting with said first member and said second member; and

means for generating a magnetic field across said electrorheological magnetic fluid such that a shear resistance characteristic of said electrorheological magnetic fluid is changed to thereby control relative rotational movement between said first and second members.

2. The damper of Claim 1 wherein said first member comprises a cylinder rotatably engaging said second member, and/or

wherein said second member comprises a housing rotatably engaging said first member, and/or

wherein said means for generating a magnetic field comprises permanent magnets, and/or

wherein said means for generating a magnetic field comprises electromagnets, and/or

wherein said means for generating a magnetic field comprises a combination of electromagnets and permanent magnets.

3. The damper of Claim 1 further comprising:

a housing coupled to said second member containing said ERM fluid; and

an extension of said first member rotatable engaging said housing and coacting with said ERM fluid.

4. The damper of Claim 3 wherein said housing supports said means for generating a magnetic field.

5. An electrorheological magnetic fluid-based rotary motion damper comprising:

an input shaft;

a first member coupled to said input shaft;

a cylinder coupled about said first member;

a second member rotatably supported about said input shaft;

a housing circumferentially coupled about said second member, said housing receiving said cylinder therein such that said cylinder is rotatable relative to said housing;

an electrorheological fluid disposed in said housing coacting with said housing and said cylinder; and

means for generating a magnetic field over said electrorheological magnetic fluid such that a shear resistance characteristic of said electrorheological magnetic fluid is changed to frictionally control said relative rotational movement between said cylinder and said housing.

6. The damper of Claim 5 wherein said first member further comprises:

an inner hub coupled to said input shaft; and

a plurality - of arms radially projecting from said inner hub for supporting said cylinder, and/or

wherein said second member further comprises:

an inner hub rotatably supported about said input shaft; and a plurality of arms radially projecting from said inner hub for circumferentially supporting said housing, and/or

wherein said means for generating a magnetic field is supported by said housing, and/or

wherein said housing further comprises:

a first chamber supporting said cylinder and said ERM fluid; and

a second chamber supporting said means for generating a magnetic field, and/or

wherein said housing further comprises:

a vertical chamber; and

a horizontal chamber bisecting said vertical chamber into an upper chamber and a lower chamber, said means for generating a magnetic field being disposed in spaced relation across said horizontal chamber in said upper chamber and said lower chamber, said cylinder being located within said horizontal chamber, and said electrorheological magnetic fluid being disposed in said horizontal chamber substantially encompassing said cylinder, and/or

wherein said means for generating a magnetic field comprises one of the group consisting of permanent magnets and electromagnets, and/or

wherein said means for generating a magnetic field comprises a combination of electromagnets and permanent magnets.

7. An ERM fluid-based rotary-motion damper for controlling deployment of spacecraft appendages comprising:

an input shaft;

a first mounting hub coupled to said input shaft;

a first plurality of ribs radially projecting from said hub;

a cylinder a)dally extending from said plurality of ribs;

a second hub rotatable supported about said input shaft;

a second plurality of ribs radially projecting from said second hub;

an annular housing circumferentially supported on said second plurality of ribs;

said annular housing having a generally cross-shaped cross-section including a vertical chamber and a horizontal chamber;

said cylinder being disposed within said horizontal chamber and being rotatable relative to said annular housing;

ERM fluid disposed in said horizontal chamber coacting with said housing and said cylinder; and

means for generating a magnetic field disposed in said vertical chamber for causing said ERM fluid to exhibit a given shear stress characteristic to control relative rotational movement between said cylinder and said housing and dampen said deployment through said input shaft.

8. The damper of claim 7 wherein said means for generating a magnetic field comprises permanent magnets, and/or

wherein said means for generating a magnetic field comprises electromagnets, and/or

wherein said means for generating a magnetic field comprises a combination of electromagnets and permanent magnets.

9. The damper of claim 7 wherein said electrorheological magnetic fluid comprises an oil vehicle, magnetizable particles, and a dispersing.

10. The damper of Claim 9 wherein said oil vehicle has a vapor pressure characteristic less than 10^{-3}mm Hg (0.13 Pa) over a temperature range of -60° to 200°C, and/or

wherein said oil vehicle is liquidic over a temperature range extending from -60° to 200°C, and/or

wherein said magnetizable particles comprise at least one of the group consisting of iron, cobalt, nickel, and magnetizable rare earth oxides.

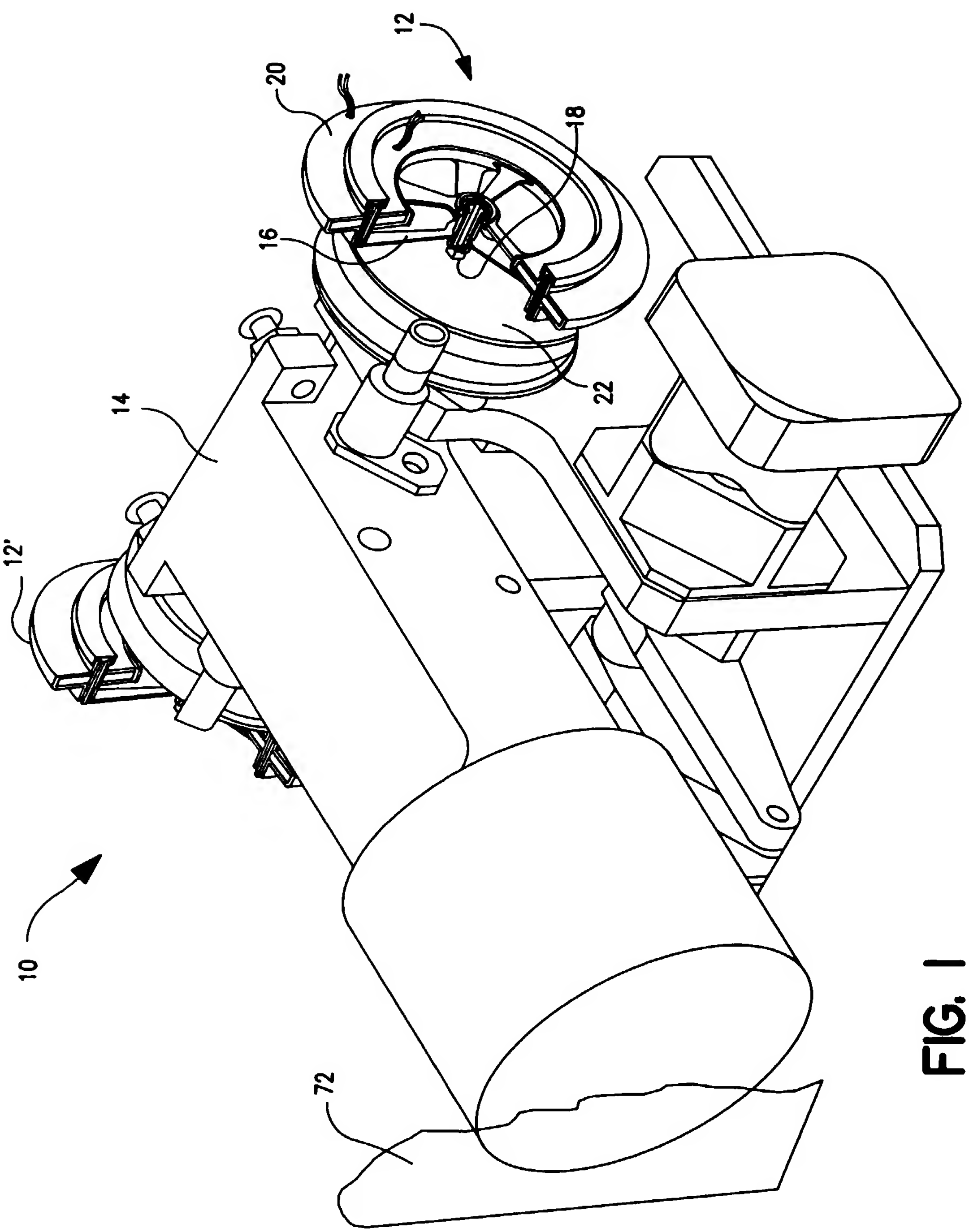

FIG. 1

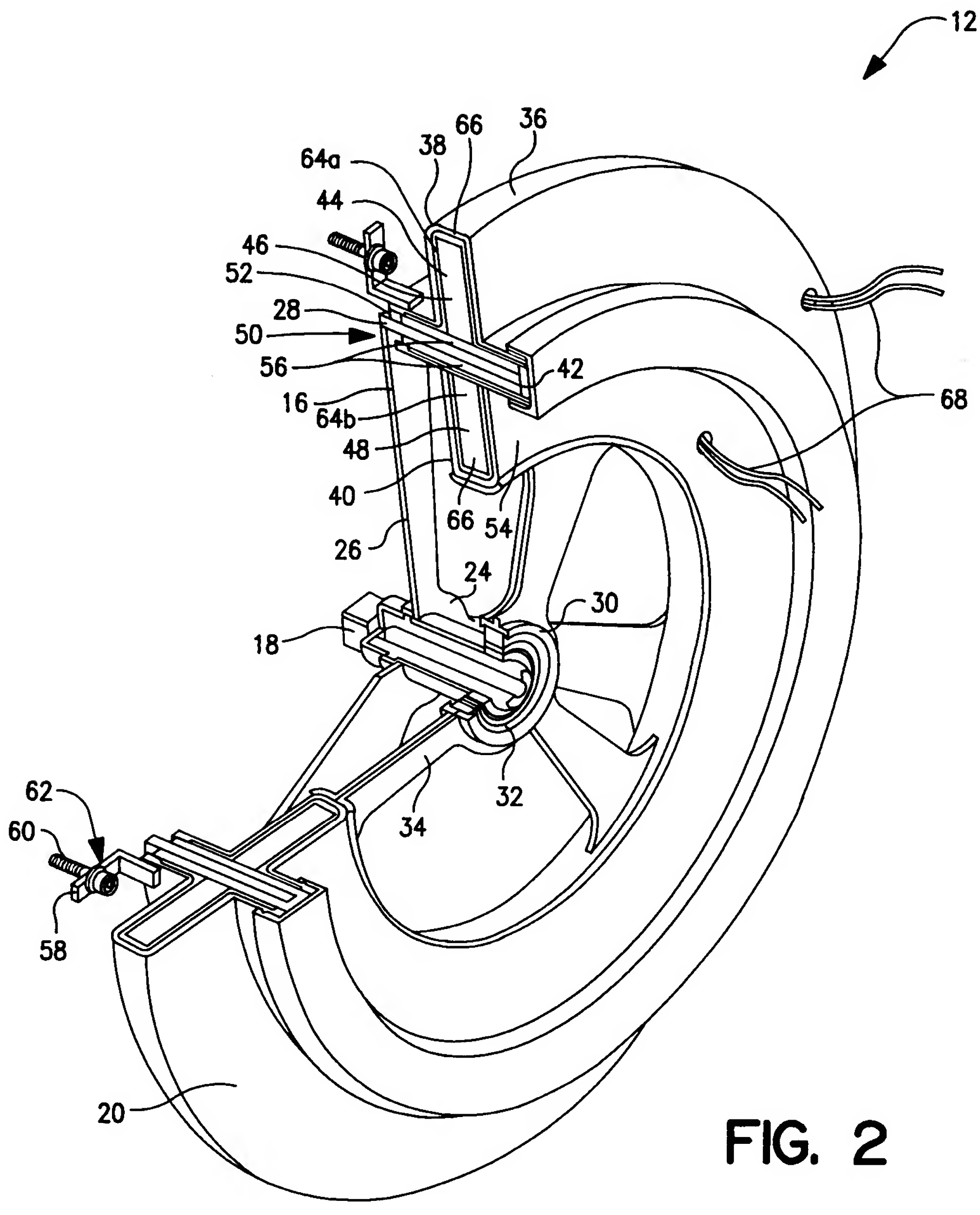
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FIG. 2

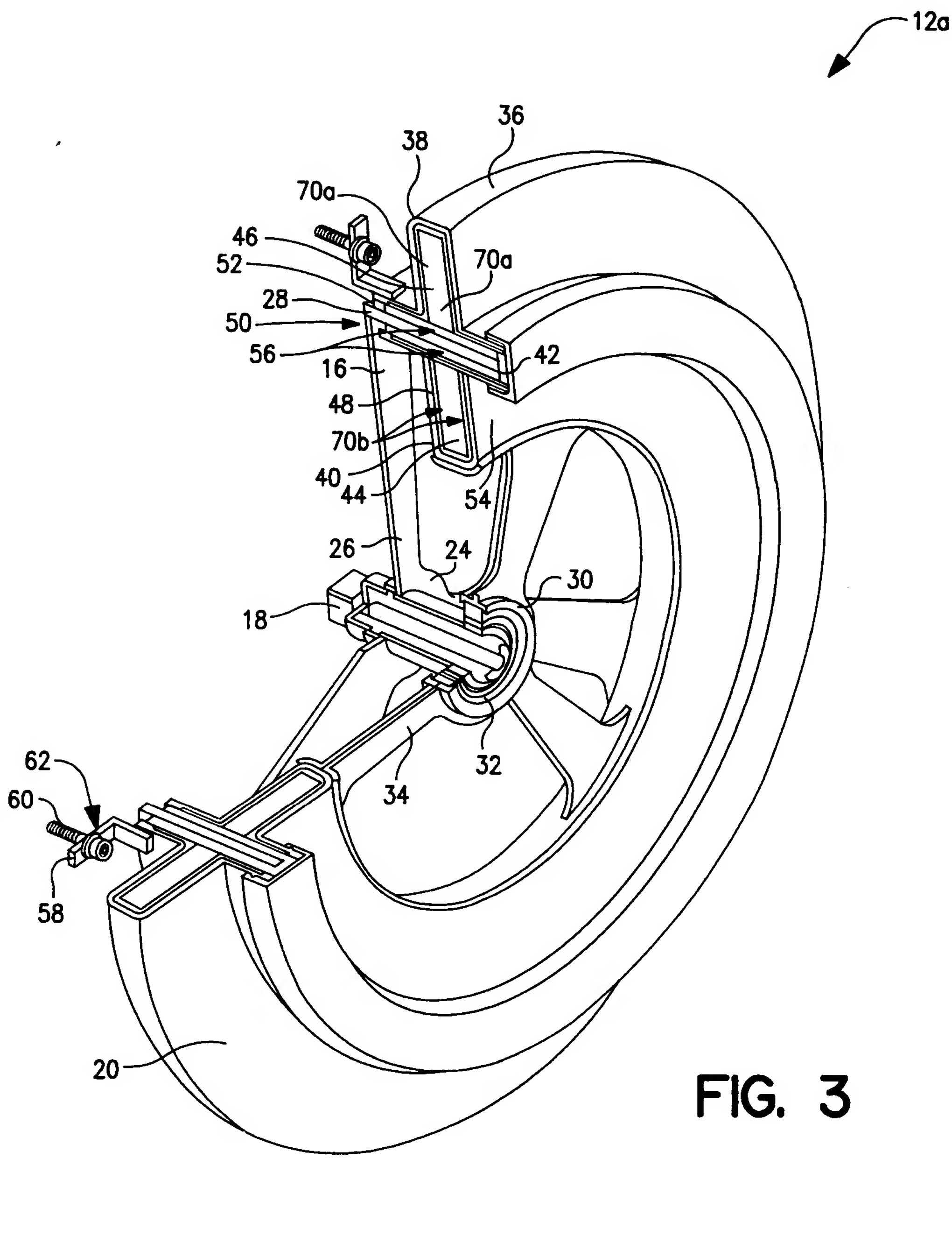
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FIG. 3

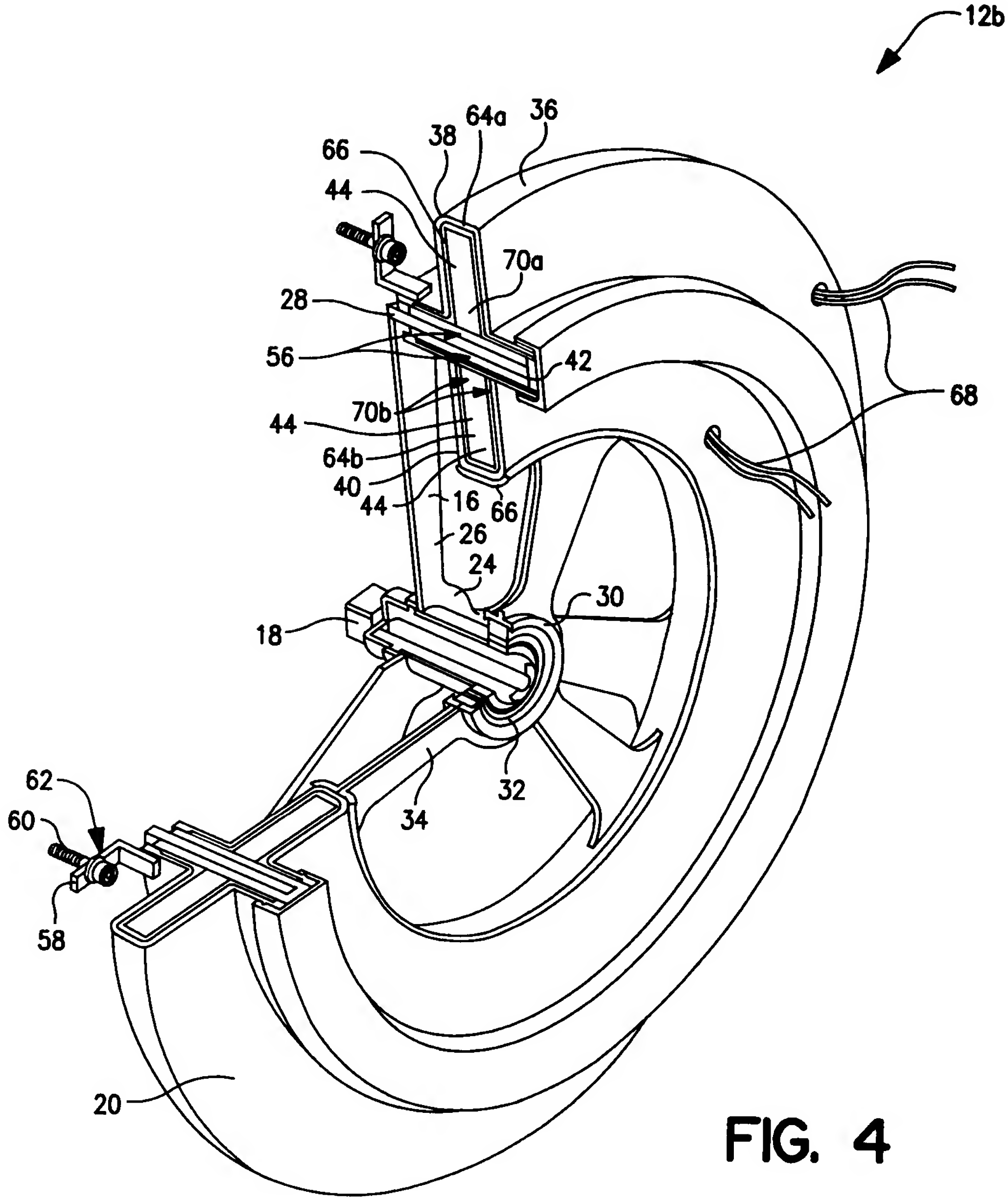
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FIG. 4

European Patent Office

EUROPEAN SEARCH REPORT

Application Number
EP 98 10 6448

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.6)
X A	US 5 573 088 A (DANIELS JOHN J) 12 November 1996 * column 8, line 61 - column 9, line 17 * * column 24, line 1-24 * * column 39, line 61 - column 41, line 25; figures 5A,5B,25A-28D *	1-6 7	F16F9/53
X A	US 5 492 312 A (CARLSON J DAVID) 20 February 1996 * column 3, line 11-20 * * column 3, line 66 - column 4, line 26 * * column 5, line 39-50; figures 1,3A-D *	1-4 5-7	
X	GB 2 275 661 A (JAGUAR CARS) 7 September 1994 * page 5, line 29 - page 6, line 14 * * page 7, line 2-8; figures 3,4 *	1-4	
X A	US 5 553 514 A (WALKOWC JANUSZ) 10 September 1996 * column 7, line 15-34; figures 5,8,9 *	5,6 7	**TECHNICAL FIELDS SEARCHED (Int.Cl.6)** F16F F16D
A	US 5 284 330 A (CARLSON J DAVID ET AL) 8 February 1994 * column 12, line 8-20; figures 1,3,10A,10C *	2,6,7	
A	DE 41 34 354 A (SCHAEFFLER WAELZLAGER KG) 22 April 1993 * column 3, line 61 - column 4, line 25; figures *	5-7	
A	US 5 267 633 A (ENDO SHIGEKI ET AL) 7 December 1993 * column 8, line 49-65; figures 3A,3B *	5-7	

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The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
BERLIN	23 July 1998	Pöll, A

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
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D : document cited in the application
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EUROPEAN SEARCH REPORT

Application Number
EP 98 10 6448

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.6)
A	GB 2 282 863 A (VINTEN GROUP PLC) 19 April 1995 * figures 1,2 * -----	6,7	

TECHNICAL FIELDS SEARCHED (Int.Cl.6)

The present search report has been drawn up for all claims

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